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Proposal "pilot program on the influence of residual stress on column strength", 1951

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220A.3 10-22-51

The Influence of Residual Stress on Column Strength

A PROPOSED PILOT INVESTIGATION

Background

In 1946 Research Committee "D" (Columns in Frames) of Column Research Council recommended that the effect of residual stress should be studied.

Since that time, although no Column Research Council projects have been set up, a certain amount of additional work has been done. Osgood has discussed the general problem in a paper presented to the First Congress of Applied Mechanics. Work has been done at the University of Illinois. At Lehigh the influence of residual stress on column strength is being studied both analytically and experimentally. The experimental work is summarized in Enclosure I, (pages 16-20 of Progress Report M to the Lehigh Project Committee.) Enclosure II contains theoretical curves from the report "Residual Stress and the Yield Strength of Steel Beams". The magnitude and distribution of residual stress was measured at Lehigh and reported upon by Luxion and Johnston (1).

The studies mentioned above have shown that a satisfactory "column curve" for a concentrically loaded steel column cannot be obtained on the basis of small coupons cut from various places in the cross-section. However, in one Lehigh study,

(1) "The Plastic Behavior of Wide Flange Beams", Progress Report No. 1, Welding Journal, Vol. 27 (11), 1948, 538s,

good correlation has been obtained between column tests and a theoretical curve determined by applying the tangent modulus concept to an average stress strain curve of a full cross-section test. See Figure b of Enclosure I. Since (1) the Column Research Council has gone on record to adopt the tangent modulus formula, and (2) applied to coupon test results this formula will not properly predict the strength of as-delivered steel columns, it is thus necessary to explore further a means of accounting for residual stress in the tangent modulus concept ... or else to modify the statement.

The good correlation between column and cross-section tests mentioned earlier was for a condition in which the columns were free to bend about the strong axis, no end rotation being allowed about the y-y axis. Since greater reductions are expected in columns free to bend about the minor axis, the possible application of cross-section tests for such members should be explored.

Scope

The first step is a pilot investigation to determine the scatter to be expected in the column curve determined from the cross-section test. The proposed program below outlines such a study; only steel columns are considered.

Following the pilot investigation it will be necessary to study the various cross-section shapes used as columns and a separate program for this study is in preparation.

It is emphasized that this is only a pilot investigation. A more general and inclusive proposal is in preparation. An outline of variables in the residual stress problem is presented at the end of Appendix I. It is recommended that Committee A of the Column Research Council prepare a statement outlining the complete problem. Material may be drawn from this proposal if desired.

Proposed Program

It is proposed to carry out the pilot program on 8WF31 shapes only along the following lines:

1. Cross-section tests
2. Coupon tests
3. Measurement of residual stress
4. Annealed cross-section test
5. Full length column test
6. Development of a test procedure and routine for handling the data

The following table indicates the correlation between heats and rollings that is considered desirable and indicates the number of tests necessary. The sequence of tests would be:

IIA1

IIA2

IA2

IB2.4

IB2.3, part of another program, will be carried on simultaneously.

PILOT PROGRAM

Table of Tests: 8WF31 Material

Heat No.	Ingot (Rolling)	Piece No.	Cross-Sect.		Coupon		Resi- dual Stress	Column Test		Sketch (Fig.1)
			As Del'd	Norm- alized	Ten.	Comp.		As Del'd	Norm- alized	
Tests completed and reported in Progress Report M										
I	B	2.2	T3	-	-	-	Yes	T15 T18	-	B & Fig.b
	B	2.1	-	-	Yes	Yes	-	-	-	D
	A	2	-	-	Yes	Yes	-	T11	-	-
Proposed tests										
I	B	2.3	-	-	-	-	-	*a,b	-	Fig.b
	B	2.4	-	Yes	No	Yes	Yes	-	c**	E
	A	2	Yes	-	Yes	No	Yes	-	-	E
II	A	1.1	Yes	-	Yes	Yes	Yes	-	-	A
	A	2.4	Yes	-	No	No	Yes	-	-	C

* Pinned about the y-y ("weak") axis. $L/r \approx 56$ and 85
 ** $L/r = 85$

Discussion of Program - Test Methods

1. Cross-section Tests

The program is built around the test of three cross-sections (IA2, IIA1, IIA2)*. Together with completed test IB2.2 this covers two heats, two rollings of one heat, and two locations in one ingot. It is the scatter of the resultant column curve that is of predominant interest in the pilot program.

One normalized cross-section is tentatively recommended (IB2.4).

The test procedure is to be the same as used in the previous Lehigh study.

2. Coupon Tests

Coupon tests must be made for each cross-section test with the exception of IIA.2. Of primary importance is the magnitude of lower yield point; all cross-section test results would be related to this value.

Tension coupons of 8" gage length give a better indication of over-all material properties than do compression tests. Tension tests are less expensive. Two sets of compression specimens are indicated (IIA.1) (IB2.4) although it has previously been indicated that tension and compression properties are very nearly the same. Further, the exact shape of the knee is not of interest. The material will be saved

* IA2 indicates piece No. 2 of ingot A of heat No. 1.

so that additional compression tests may be made if necessary.

Tests will be carried into the strain-hardening range in order to collect further data on this property. Specimens are to be selected from locations free from cold-bending yield lines if possible.

In the case of compression tests, coupons should be taken from each location of Figure D. In the case of tension coupons stations 1, 2, 5, 8 may be adequate.

3. Residual Stress

A Whitmore gage (10" gage length) will be used with the sectioning technique previously used (1).

It is recommended that the residual stress be measured for each cross-section test. The variation in residual stress may be large and this variation could be an explanation for any large amount of scatter obtained. For any one rolling it is expected that the cooling residual stress pattern will be rather uniform.

A second study will be made of the relaxation of residual stress due to the gradual removal of material from the ends. This will be done on the first test (IIA1).

4. Column Tests

Three column tests are proposed, two of which would be carried out on a separate project. The normalized column is proposed on a tentative basis, since the probable straightness of the column after normalizing is somewhat in doubt. In

general, such tests should be deferred to the full program.

The two as-delivered column tests recommended involve columns 8' and 14' 6" in length, pinned about the weak axis ($L/r \approx 56$ and 85). Columns 11, 15, 18, shown in Enclosure I, were "pinned" about the strong axis and "fixed" about the weak axis so that deflection should theoretically begin in the strong direction. Final collapse occurs by combined bending and twist. The L/r of the proposed tests is indicated on Figure b of Enclosure I.

5. Test and Analysis Procedure

Part of this work of laying out a standard procedure for handling tests and data work has been done, but it is proposed to formalize it as a phase of the pilot investigation. Since numerous institutions may engage in later work, this part of the program is important.

The following data at least should be reported:

- (a) stress-strain curves similar to Fig. a of Encl. I
- (b) column curves - similar to Fig. b and on a theoretical basis to Encl. II
- (c) residual stress distribution
- (d) magnitude of load and location of first yield lines - other than at the end
- (e) data from mill report

The following data also should be collected:

- (a) mapping of yield lines prior to test
- (b) mapping of yield lines during test

Conclusions

These tests should indicate whether or not an extensive investigation of cross-section tests is advisable.

No separation has been made between the stress-strain property study separately proposed by Committee A and the residual stress problem. For rolled shapes they are inseparable. Later tests should be made of angles and channels and coupons from plate material. These should be part of the larger program being outlined separately.

Budget

It is considered that 8 months will be adequate for the completion of this work. The following budget is proposed:

SALARIES & WAGES

Supervision	\$ 300.00
Research Personnel (part-time)	800.00
Wages (mechanics student help, stenographers)	1060.00
	<hr/>
	\$2160.00

OVERHEAD at 33 1/3% 720.00

MATERIAL 100.00

MISCELLANEOUS 300.00

CONTINGENCIES 320.00

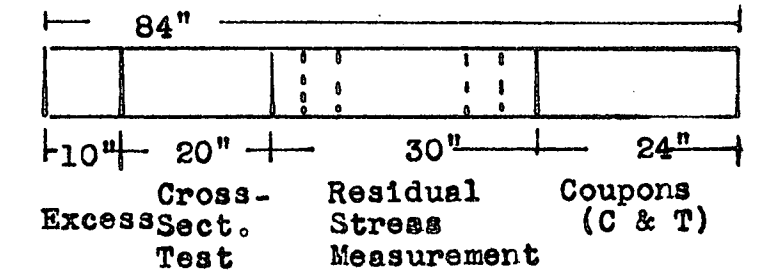
\$3600.00

The work would be carried out in the Fritz Engineering Laboratory at Lehigh University.

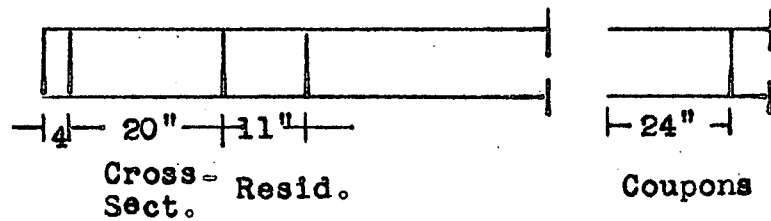
Respectfully submitted,

Lynn S. Boodie

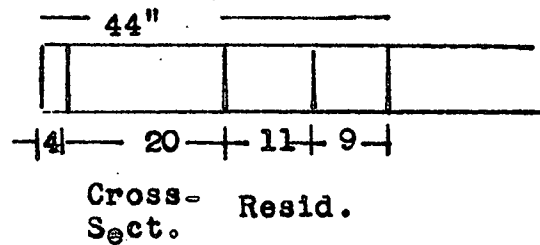
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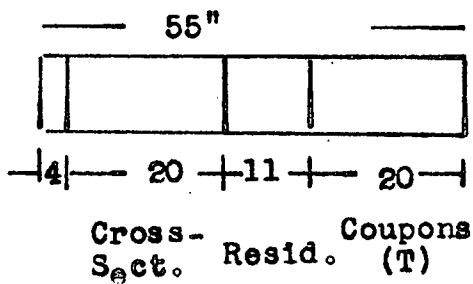
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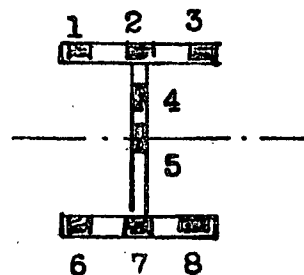
B



C



E



D

Location of Coupons

Figure 1 - Cutting diagrams for residual stress program.

17 September 1951

File No. 2204

TO: MEMBERS, LEHIGH PROJECT SUBCOMMITTEE

RESIDUAL STRESSES IN COLUMNS

Gentlemen:

You have undoubtedly noticed in the recent Quarterly Progress Reports that we have often mentioned the subject of residual stresses. This stems from the fact that early in the experimental work yielding was observed in the flanges of WF sections at lower loads than predicted on the basis of coupon tests. The Lehigh Project Subcommittee recommended that residual stresses be measured early in the program and some results were presented in the first progress report of the project (Welding Journal, November 1948).

Since 1949, Dr. Bruce Johnston has been emphasizing the importance of residual stresses in reducing the critical load in columns. Then a column test was carried out (part of the approved program) showing a reduction in strength over that predicted on the basis of small coupon tests. The problem has also been treated theoretically in Progress Report 6. As part of a course project, Mr. Huber then carried out a pilot program in which he tested a 20" length of an 8WF31 member with flat ends. Hereafter this is called the "residual stress specimen". An average stress-strain diagram was obtained which was used to compute a column curve according to the tangent modulus concept.

It is the purpose of this letter to show the correlation between the results of pin-ended column tests and the theoretical column curve based on the above average stress-strain diagram. A preliminary report has been prepared and will be distributed after further editing.

In Fig. a is shown the stress-strain diagram as determined by strain measurements on a small coupon as compared with the average stress-strain curve for the full 8WF31 cross-section containing residual stress. Measurement for the latter were made with a simple dial gage technique, readings being taken at each of the four corners over a gage length equal to that of the specimen.

In Fig. b are shown column curves determined from the tangent modulus of the curves shown in Fig. a. Plotted upon the curve are the critical loads of three tests at slenderness ratios of approximately 28, 42 and 56.

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(Residual Stresses) 17

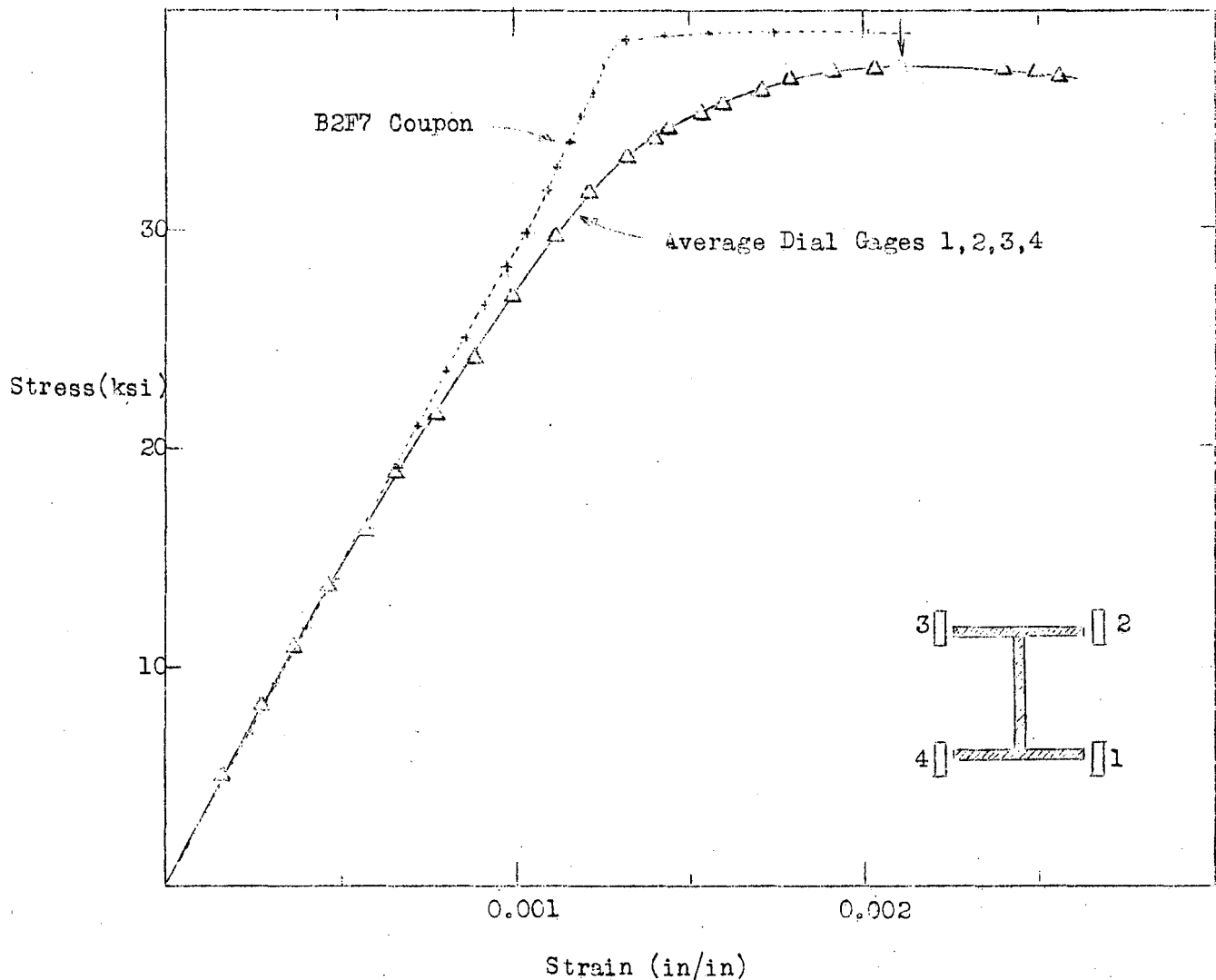


Fig. a

This study of a short compression specimen resulting in the curve of Fig. b is only a pilot investigation. However present evidence indicates the following:

- (1) A satisfactory column curve cannot be obtained on the basis of tests of small samples cut from various places in the cross-section.
- (2) From Fig. b, as expected, the percentage reduction is greatest in the range $L/r = 90$. No tests fell in this range and they should be done.
- (3) Good agreement with the column curve is obtained for T11 and T18. T15 carries less load than predicted on the basis of the average curve determined from the "residual stress specimen".

220A.3 Encl. I

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(Residual Stresses) 18

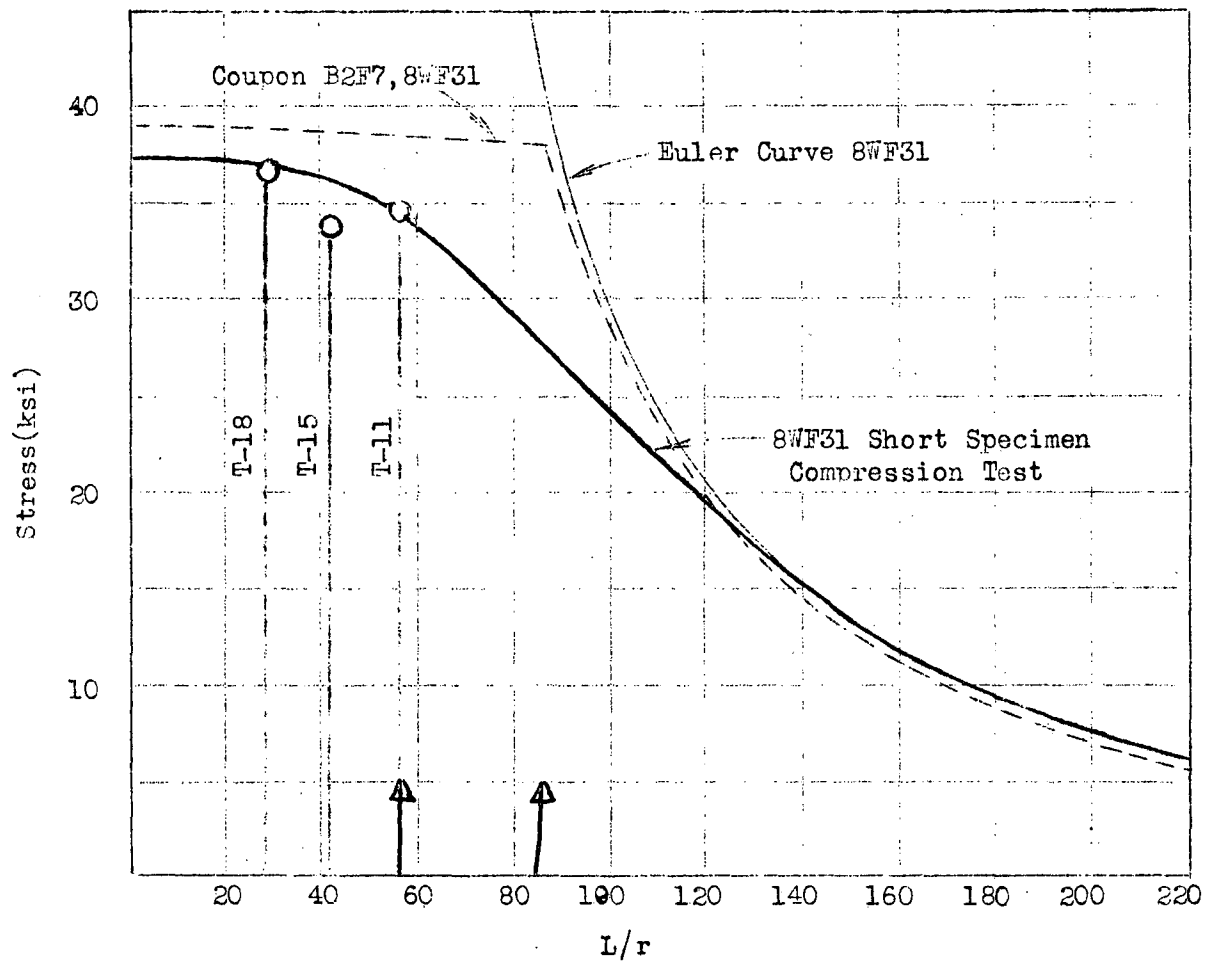


Fig. b

- (4) The column specimens came from two ingots of steel from the same heat. T11 came from one rolling ("A" material) and T15, T18 and the residual stress specimen came from the second rolling ("B2" material). The residual stress level has not been measured as yet for the "A" material.
- (5) The three columns should theoretically buckle about the "strong" axis of the section by virtue of the "fixed end" condition against bending about the weak axis. In each case, however, final failure was by combined bending and twist.
- (6) A theoretical curve could be drawn in Fig. b for collapse on the basis of the "effective I" concept discussed in Progress Report 6, section VII. This curve would be below the column curve determined from the "residual stress specimen".

Through arrangements with the Bethlehem Steel Company the project staff visited their plant and observed the rolling, cooling, and cold-straightening of 8WF31 specimens (the same shape as used in the column test program). Other shapes were examined after cold-straightening. The purpose of the visit was to determine at what stage in the process the "yield lines" were formed, since nearly every steel member delivered shows evidence of prior plastic strain. The following comments are made as a result of this examination:

- (1) Almost without exception every steel member is cold-straightened in a process that consumes a considerable amount of time.
- (2) For the sections observed there are no "yield lines" present in the specimens after cooling and prior to cold-straightening. During the "gagging" process, the formation of local plastic yield zones could clearly be seen (Examples of "yield lines" are shown in Progress Report 6, Figs. 30 and 31).
- (3) There is plastic deformation of the flange center during the cooling process, a process which is basically responsible for the formation of cooling residual stresses. However, the mill scale in the region contains no yield lines, although it often has a rough appearance.
- (4) In making residual stress measurements in rolled specimens one should note carefully the location of "yield lines" in the mill scale, since they are evidence of a cold-straightening pattern. Cooling residual strain measurements should of course be made where

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(Residual Stresses) 20

there are no local yield zones, else erroneous conclusions as to the yield stress level may be drawn.

- (5) Coupons for material property tests should also be selected taking care to note the cold-bending yield lines. Specimens which have been cold-worked will give a different result than those which have not and it is tentatively suggested that specimens be taken from portions which have not been cold-straightened for more representative indication of the strength of a member.
- (6) There will certainly be variation in residual stress along a member and across the section. However it is expected that the cooling residual stress pattern will be rather uniform and that the greatest variations will be due to the local areas of cold-bending.

Research Committee 4 of the Column Research Council has recommended that research on residual stress be carried out and we hope to be able to participate in this work. Among the early investigations that are worthwhile is a study of the residual stress as influenced by shape of cross-section. A tentative chart organizing the overall residual stress problem has been prepared for criticism and follows.

RESIDUAL STRESSES IN COLUMNS

- I. Mechanism for the Development of Residual Stress
- II. Magnitude and Distribution of Residual Stress
 - A. Type of Material
 - B. Cross-sectional Form
 - C. Method of Fabrication (rolling, welding)
 - D. Variation along a Member
 - E. Variations through the Thickness
- III. Influence of Particular Residual Stress Patterns on Column Strength
 - A. Type of Material
 - B. Cross-sectional Form
 - C. End Restraint
 - D. Loading (including combined bending and axial load)
 - E. Variation with L/r
- IV. Technique - How to Develop Column-Strength Curves for Materials with Residual Stress
 - A. Measurement of Residual Stress
 - B. Testing full cross-section
 - C. Comparison of "Coupon" Tests with Cross-section Tests.

Sincerely yours,

Lynn S. Beedle
For The Project Staff

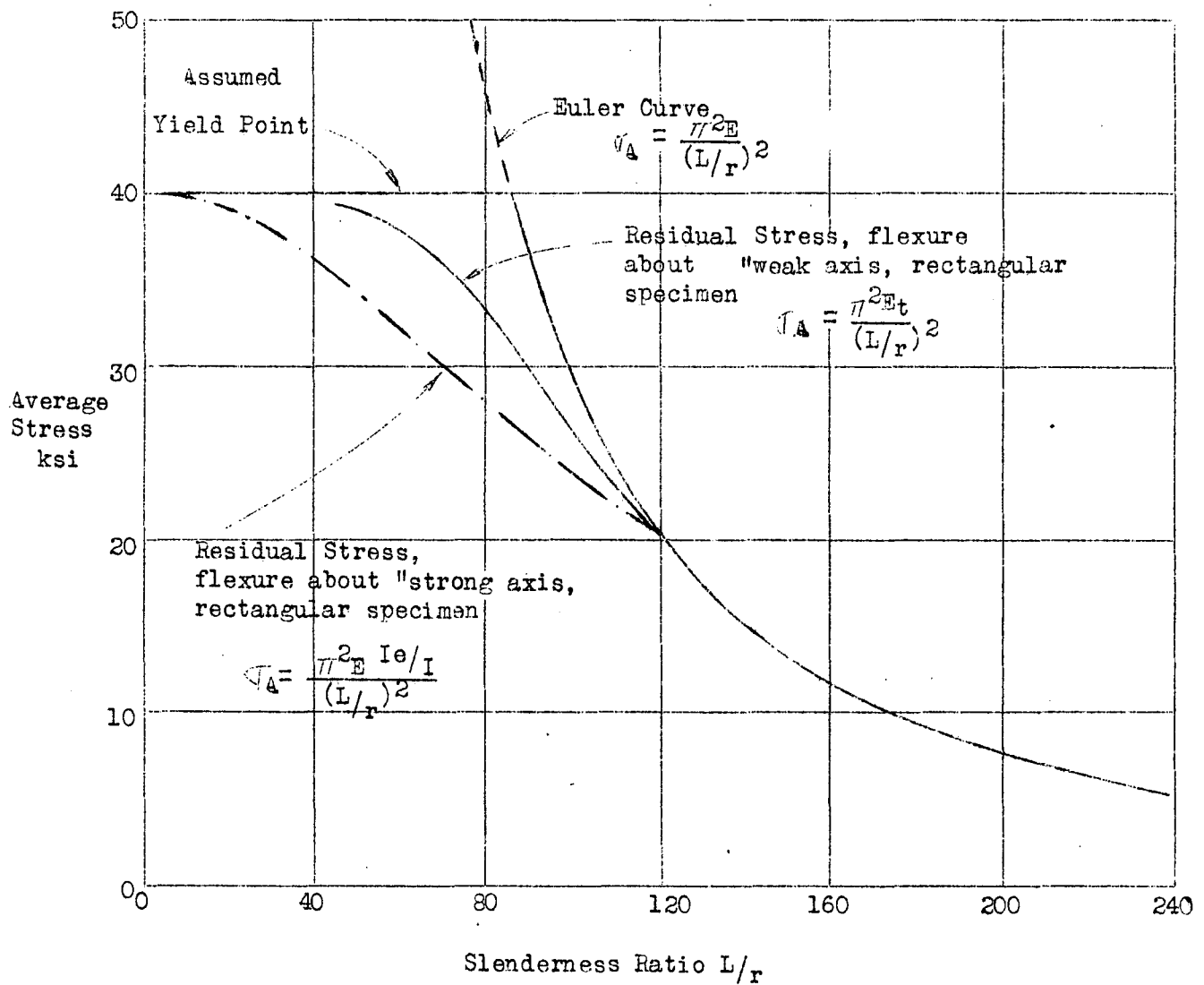


Figure 46 of the Report, "Residual Stress and the Yield Strength of Steel Beams"